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(Vol. XIV.—January, 1885.)

EXPERIMENTS ON THE FLOW OF WATER IN A 48-INCH PIPE.

By F. P. STEARNS, M. Am. Soc. C. E.

READ OCTOBER 1ST, 1884.

WITH DISCUSSION.

These experiments are a part of the series made upon the Boston Water Works a few years since, and a brief mention of them has already been made in a previous paper.* The chief interest in them is due to the fact that they are beyond the limit of previous carefully conducted pipe experiments, both in size of pipe and volume of water.

The pipe was on the line of the Sudbury Conduit, being used to carry water across a valley. It was a cast-iron pipe, coated with Dr. Angus Smith's coal-tar preparation, and several measurements showed that it had been cast very exactly 48 inches in diameter. The different sections, each 12 feet long, fitted one another well. In plan the pipe

* Description of some Experiments on the Flow of Water, by A. Fteley and F. P. Stearns, Transactions of the Society, Vol. XII, No. CCLIII, January—March, 1883.

was straight. In elevation it was sloping at either side of the valley at the rate of 17 feet per 100, and between these slopes, in the bottom of the valley, it was nearly level and under a head of 48 feet. The length of the level portion was 1 124 feet, being a little more than two-thirds of the total length of 1 747 feet. The changes in direction were made by two vertical curves, one of 500 and the other of 1 170 feet radius. The mean pressure on the pipes during the experiments was 41 feet. The pipes had been laid three years, and had been in use two, when the experiments were made, yet the tar coating presented nearly as good a surface as when it was new.

The formula adopted for calculating the results is one frequently used for flow in pipes and channels. It is :

$$v = c \sqrt{RI},$$

in which

v = velocity in feet per second,

c = a co-efficient,

R = the mean radius, or hydraulic mean depth,

I = the sine of the inclination, or loss of head per unit of length.

In pipe experiments, the data required to obtain the value of c in the formula quoted are the diameter and length of the pipe, the volume flowing, and the loss of head due to the resistance to flow within the pipe. The diameter and length being already known, only two unknown quantities remain.

The volume flowing was measured at a weir about 10 miles distant up the conduit from the pipe, and to this measurement three-tenths of a cubic foot per second was added for filtration into the conduit below the weir. The amount of the filtration was determined from fairly good data; but, even if somewhat inaccurate, it has little importance, as its whole effect was less than 1 per cent. The weir used was 19 feet long, and had previously been tested by the actual measurement of the water passing over it.* The heights of the hook gauges were tested at the time of these experiments and all necessary precautions were taken to insure accuracy of measurement and a steady flow.

The loss of head in a length about 60 feet shorter than the whole length of pipe was measured. This method was adopted to avoid including in the measurement the loss of head at the entrance of the pipe,

* A description of the experiments made to test the weir is given in the Transactions of the Society, Vol. XII, February, 1883, p. 61 *et seq.*

the gain or loss at the exit, the effect of two rather sharp curves (30 feet radius) near the ends of the pipe, and several other disturbing causes.

The apparatus used for taking the heads was as follows: In each of the pipe-chambers, at either end of the pipe, there was a float-gauge designed for permanent use in measuring the height of the water in the chambers. This consisted of a vertical iron cylinder, 12 inches in diameter, plugged at the bottom; in this cylinder was a hollow brass float, with a suitably guided stem, carrying an index up and down the face of a graduated scale. Water was admitted to the float cylinder through a small pipe leading from the centre of the pipe-chamber, the flow being controlled by a stop-cock. Connected with the float-cylinder was a small brass cup, having a level top of known elevation. By filling the cylinder until the cup was even full, the position of the index was adjusted.

For the purposes of these experiments, the small pipes leading from the float-cylinders were extended into the ends of the 48-inch pipe, along its bottom, about 33 feet. The last 7 feet of each of these small pipes was a smooth, straight brass tube, with several holes drilled in its top, and with its end plugged. In the opinion of many physicists, the head measured under these circumstances would be affected by suction due to the velocity of the water passing the holes in the pipe. This view, however, seems to be conclusively disproved by the careful and numerous experiments on the subject by Mr. H. F. Mills,* who found that no such suction takes place when sufficient care is taken to have the holes in and normal to a plane surface parallel with the current. A few experiments by the writer † sustain the conclusions of Mr. Mills. It is believed that the required care was taken in these pipe experiments.

The heights of the gauges at the two pipe-chambers were compared when there was no flow, and the water, being dammed below, stood at the same level at each. This method of comparison was checked by instrumental levels, previously taken, to 0.008 of a foot. The heights of the indexes of the gauges were adjusted before the experiments, and were tested during their progress, and found not to have changed.

The precaution was taken to expel all air from the small pipes leading to the gauges, by pouring water into the float-cylinders, and so causing

* Experiments upon Piezometers used in Hydraulic Investigations, by Hiram F. Mills, C. E., p. 52, Proceedings of the American Academy of Arts and Sciences, 1878.

† Transactions of the Society, Vol. XII, January, 1883, p. 35.

a swift flow outward through the small pipes. In the last two experiments, in addition to the above, the floats were pressed down and held until some of the water had been forced out of the cylinders, and when released there was a rapid inward flow. Whether the water in the cylinders was raised or lowered, it returned after a short time to the same normal level.

The writer was unable to conduct these experiments in person, owing to other engagements, but he gave detailed instructions as to the work to be done to assistants who had previously had considerable experience in this class of work.

The features common to all of the experiments are as follows :

Diameter of pipe (D).....	4.000 feet.
Area of pipe (A).....	12.566 sq. ft.
Mean radius ($R = \frac{D}{4}$).....	1.000 foot.
Length of pipe used in the experiments, } measured along its axis.....	1 747.2 feet.
Temperature of water about 38° Fahrenheit.	

The variable features are shown in the following table :

	Experiment No. 1.	Experiment No. 2.	Experiment No. 3.	Experiment No. 4.
Date.....	May 1, 1880.	May 5, 1880.	April 26, '80.	April 27, '80.
Volume, cubic feet per second (Q).....	32.867	46.972	62.391	77.852
Mean velocity, ft. per sec. ($v = \frac{Q}{A}$).....	2.616	3.738	4.965	6.195
Total loss of head, feet.....	0.5557	1.243	2.133	3.230
Loss of head per foot (I).....	0.0003181	0.0007115	0.0012206	0.0018485
Value of c in the formula, $v = c \sqrt{RI}$	146.67	140.14	142.11	144.09

An examination of the last line of the table shows that in the last three experiments the co-efficients increase gradually with the velocity, as might be expected from existing knowledge of the subject. The first experiment appears to be anomalous, though there was nothing noted at the time it was taken to indicate why it is so.

I will next present some comparisons of these results with those

obtained by others, using for this purpose as the result of these experiments an average of the last three, as follows :

Mean velocity.....	4.966 feet.
Mean co-efficient.....	142.11
Mean value of RI	0.001221

A comparison with formulas based upon the older experiments, including the formulas of Prony, Eytelwein, D'Aubuisson, Weisbach, Neville and others, shows that they give results from 35 to 45 per cent. too low.

Darcy's formula for flow in clean cast-iron pipes is :

$$RI = \left(0.00007726 + \frac{0.00000162}{R} \right) v^2$$

For a pipe 4 feet in diameter, this formula may be reduced to the form, $v = c\sqrt{RI}$, the value of c being 112.6. This co-efficient requires to be increased about 26 per cent. to equal the one found by our experiments. The Darcy formula given above is the one usually quoted, and it was deduced by him from experiments on uncoated pipes. He made some experiments, however, in which he compared the flow in coated and uncoated pipes about 8 inches in diameter, and he found that the co-efficient deduced from the former was about 16 per cent. larger than the other.* Assuming the same ratio to hold good for 4-foot pipes, his result would be but about 9 per cent. too low.

The experiments of Hamilton Smith, Jr.,† M. Am. Soc. C. E., are not so easily comparable, as he has deduced no formula from his results. He has, however, drawn upon a diagram, representing the results of his experiments, a series of curves showing the co-efficients for pipes up to 30 inches in diameter. In order to make some kind of a comparison, I have extended this series of curves, and find for a 48-inch pipe, and a velocity of 5 feet per second, a co-efficient of 128 to compare with our experimental value of 142.1. Such a comparison as this is obviously only a rough approximation.

The experiments of J. Nelson Tubbs,‡ M. Am. Soc. C. E., on the flow

* Recherches expérimentales relatives au mouvement de l'eau dans les tuyaux. Henry Darcy, Paris, 1857, p. 106.

† The Flow of Water through Pipes, by Hamilton Smith, Jr., Transactions of the Society, Vol. XII, No. CCLIV, April, 1883.

‡ Report of the Chief Engineer of the Rochester Water Works, Jan., 1877.

through the Rochester compound pipe, gives a co-efficient of 130. The flow took place through nearly equal lengths of pipes 2 and 3 feet in diameter, but since about $\frac{1}{10}$ of the loss of head occurred in the smaller pipe, the co-efficient may be considered as applicable to a pipe 2.1 feet in diameter. Correcting for the difference in the size of the pipes by curves on Mr. Smith's diagram extended as above described, the Rochester experiment would give for a 48-inch pipe a co-efficient of about 140.5; and a further slight correction, due to the velocity in the Rochester pipe being somewhat smaller than in the Boston one, will increase the co-efficient until it nearly coincides with that found by us. Other methods of correcting for the difference in the sizes of the pipes would have given nearly the same results.

Mr. J. T. FANNING, M. Am. Soc. C. E., gives in his work* a table of velocities in clean iron pipes corresponding to given slopes and diameters. For the conditions given in our experiments, the velocity taken from the table is 4.61 feet per second, while the observed velocity was 4.966 feet, the difference being between 7 and 8 per cent.

The writer examined the experiments made by Dr. Lampe at Danzig, but since they vary both in velocity and size of pipe from our experiments, they are not readily comparable with them.

The results of his experiments appear to be somewhat larger than those of Hamilton Smith, Jr. These experiments of Lampe seem to be a valuable addition to the existing data on flow in pipes, and the writer having reduced them to feet measures, will give their principal features in an appendix.

In addition to the experiments which are the subject of this article, some others were previously made in the same locality, the flow taking place through two 4-foot pipes at the same time. In these experiments the total loss of head from pipe-chamber to pipe-chamber was measured. In order to obtain the friction head, so called, it would be necessary to make corrections for velocity of approach, loss of head at entrance, gain (or loss) of head at exit, and for some imperfections in the arrangement of the small pipes leading to the gauge-cylinders. In two out of the three experiments, the case was further complicated by the large pipes not being full at their upper ends.

* A Treatise on Water-Supply Engineering, by J. T. Fanning, New York, 1877, p. 262.

Without making any of the above corrections, the following results are obtained :

Velocity.	Co-efficient.
2.497 feet per second,	130.2
3.121 " " "	130.6
4.437 " " "	136.1

If, in the last experiment, the head is corrected for loss at entrance, upon the assumption that the head lost was only that theoretically required to produce the velocity, then the co-efficient becomes 148.5 instead of 136.1. This is only one correction of several that should be made, but for making which there are no data.

These three experiments are given only as a rough check, tending to show that the others are not unreasonably large in their results.

Some of the experiments of Darcy and Bazin * show that the same co-efficient may be applied to a tube running full or half full. Assuming this to be true, some of their experiments with channels may be compared with our pipe experiments. They give for a semi-circular channel, about 4 feet in diameter, lined with pure cement, and running nearly full with a velocity of 6 feet per second, a co-efficient of 154 ; while our pipe experiments with the same velocity gave but 144. When the same channel was lined with cement, mixed with one-third fine sand, the co-efficient corresponded quite closely with that obtained from the pipes.

From the comparisons that have been made, it may be inferred that our experiments have furnished unusually, but not unreasonably, high results ; also that the older formulas are entirely inapplicable to new, large coated pipes. On the other hand, a formula giving as high results as our experiments would be inapplicable to uncoated pipes, or to any pipes in which, on account of long use, tubercles had begun to form.

* *Recherches Hydrauliques*, pp. 176, 177.

APPENDIX.

ABSTRACT OF DR. LAMPE'S EXPERIMENTS ON THE FLOW
THROUGH A PIPE-CONDUIT OF THE DANZIG WATER
WORKS.*

The flow took place through a cast-iron coated pipe of English manufacture, 1.373 feet in diameter. The sections of pipe were each 12 feet long, and there were no sharp bends. The length of pipe used in the experiments varied from $4\frac{1}{2}$ to 6 miles. The pressures were measured at many points by a mercury pressure gauge, and the hydraulic grade line was found to be practically straight. Four experiments were made, but the first, a preliminary one, was not considered accurate.

Other features of the experiments are shown in the following table:

	Experiment No. 1.	Experiment No. 2.	Experiment No. 3.	Experiment No. 4.
Date.....	Oct. 17, '69.	Mar. 19, '71.	Oct. 8, '70.	Oct. 1, '70.
Volume, cubic feet per second, (Q).....	4.575	4.011	3.671	2.334
Mean velocity, ft. per sec. ($v = \frac{Q}{A}$).....	3.090	2.709	2.479	1.577
Mean radius, (R).....	0.3432	0.3432	0.3432	0.3432
Loss of head per foot, (I).....	0.00195	0.00163	0.001376	0.0005915
Value of c in the formula, $v = c\sqrt{RI}$	119.4	114.6	114.1	110.7

DISCUSSION.

RUDOLPH HERING, M. Am. Soc. C. E.—In connection with this subject, I would like to allude to Kutter's formula. In a paper I read before the Society, October 16th, 1878,[†] advocating the use of this formula, because it appeared to be the most rational one then known, and I believe known to this day, I gave, page 11, values of n (co-efficient of roughness) deduced from numerous experiments, and suggested the value of $n=0.011$ for iron pipes. This gives a value for the co-efficient c , in Mr. Stearns' paper, of 141, or substantially equal to the one obtained from his experiments, which was 142.11.

* Der Civilingenieur, 1873.

[†] Transactions of the Society, Vol. VIII, No. CLXXVI, January, 1879.

The effect of the roughness of the wetted perimeter is so great that, for instance, when the surface is equal to that of

A plaster of pure cement, the co-efficient would be 156, or

“ “ cement, with $\frac{1}{2}$ sand, “ “ 141, “

Unplaned timber, “ “ 128, “

Brick work, “ “ 117,

the latter being 25 per cent. less than for pure cement.

The surface of a cast-iron pipe in good condition would (and I think every one will admit) have about the roughness of ordinary plaster mixed of cement and sand, and be neither as smooth as pure cement nor as rough as unplaned timber, therefore not difficult to fix within reasonable limits.

In using Kutter's formula, we would, consequently, select a co-efficient of about 141. If our judgment would indicate a greater smoothness than such a plaster, but still much less than that of a pure cement, which would require 156, we might use say 145, and the velocity ascertained would no doubt be nearer the truth than by using 141.

The proper selection of the co-efficient c , therefore, clearly depends entirely upon the judgment of the engineer, as I think it should, and is entirely out of the range of a purely theoretical consideration, because, how is it possible, with our present knowledge, to introduce the feature of roughness, a slight variation of which in the above cases exercises such a great effect, otherwise than by judgment?

When in Europe the last time I was pleased to see how the use of Kutter's formula was extending, the only drawback seeming to be its complicated structure. But diagrams were being gradually substituted for it.

As far as eight years of my own experience goes with the diagram I presented to the Society (Transactions, January, 1879), but limited to small channels, I can state that the results have been far more satisfactory than those obtained from the old formulas, and that the labor of calculation was reduced to a minimum.

SAMUEL H. YONGE, M. Am. Soc. C. E.—There appears to be no good reason why observation No. 1 in Mr. Stearns' paper should be discarded, as it is not apparent why and in what manner any errors should have been made in determining the value of either R , I , or v , and it seems arbitrary to reject this observation simply because it does

not fit into a formula which may not be strictly applicable to this case. In the formula, $v = c \sqrt{RI}$; the value of c , viz., 142.11, is considered a constant, in deriving which the first observation was omitted. By constructing a diagram in which the observed velocities are plotted as ordinates and the \sqrt{RI} as abscissas, it will be seen that the ratio between velocity and \sqrt{RI} is not constant, as the most probable mean line for the points evidently is not a straight line, but a curve. It also appears from such a diagram that the first observation accords well with the others. All of the observations given are therefore used in the following calculation, in which the relation between RI and v is investigated by the method of least squares on the basis of the general equation,

$$RI = Av^2 + Bv + C,$$

in which A , B and C are constants.

By substituting the values of RI and v , as determined by the observations, we derive the following observation equations, viz.:

$$.0003181 = 6.843456 A + 2.616 B + C,$$

$$.0007115 = 13.972644 A + 3.738 B + C,$$

$$.0012206 = 24.651225 A + 4.965 B + C,$$

$$.0018485 = 38.378025 A + 6.195 B + C.$$

From which the following normal equations are derived:

Normal in A .

$$.1131495040071 = 2322.623367275922 A + 430.277421168 B + 83.845350 C.$$

Normal in B .

$$.0210034731 = 430.277421168 A + 83.845350 B + 17.514 C.$$

Normal in C .

$$.0040987 = 83.845350 A + 17.514 B + 4 C.$$

Combining, substituting and solving, the following values are obtained, viz.:

$$A = .00003345534,$$

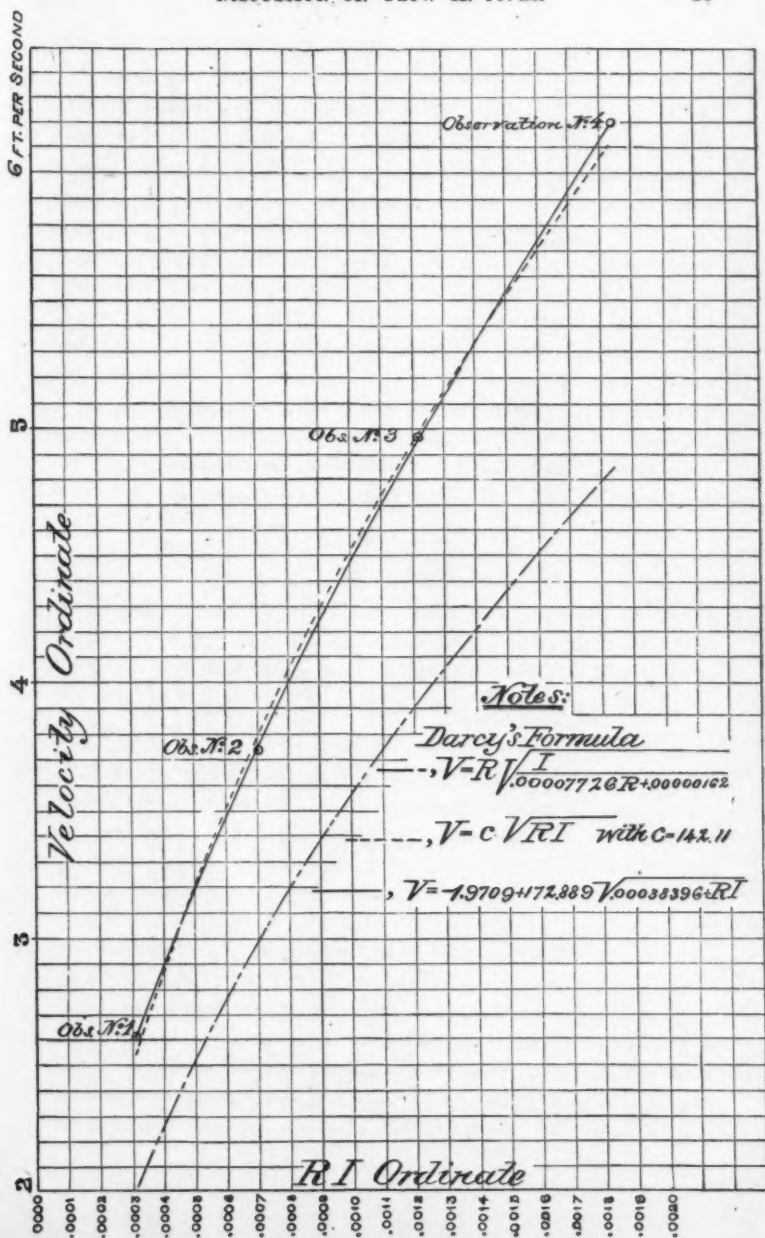
$$B = .000131874,$$

$$C = -.0002540040,$$

which, substituted in the general equation, becomes

$$RI = .00003345534 v^2 + .000131874 v - .0002540040.$$

$$\text{Hence } v = -1.970896 \pm \sqrt{11.476761052816 + 29890.594446 RI},$$



DISCUSSION ON FLOW IN PIPES.

TABLE

No. of Observation.	Value of L .	Observed Velocity.	Velocity as Computed* by Darcy's Formula.	Difference between Observed and Computed Value.	Rate of Difference %	Velocity as Computed by the Chezy Formula, $c = 142.11$.	Difference between Observed and Computed Value.	Rate of Difference %	Velocity as Computed by the Chezy Formula, $c = 143.0408$.	Difference between Observed and Computed Value.	Rate of Difference %	Velocity as Computed by the New Formula.	Difference between Observed and Computed Value.	Rate of Difference %
1	.0003181	ft. p. sec. 2.616	ft. p. sec. 2.608	..... .608	..... 23.2	ft. p. sec. 2.635	..... .081	..... 3.1	ft. p. sec. 2.651	..... .065	..... 2.5	ft. p. sec. 2.610	..... .006	..... .2
2	.0007116	3.798	3.803	..... .735	..... 19.7	3.791	..... .053	..... 1.4	3.816	..... .078	..... 2.0	3.751	..... .013	..... .4
3	.0012206	4.965	3.934	..... 1.031	..... 20.8	4.965	..... .000	..... 0.0	4.907	..... .022	..... 0.7	4.955	..... .010	..... .2
4	.0018185	5.195	4.841	..... 1.354	..... 21.8	6.110	..... .085	..... 1.4	6.150	..... .045	..... 0.7	6.198	..... .003	..... .0%
Totals	.....	.....	.....	..... 3.728	..... 85.5	.....	..... .033	..... 1.4	.....	..... .110	..... 2.7	.....	..... .016	..... .4
Average difference = 21.4%. Maximum difference = 23.2%. Minimum difference = 19.7%.														
Average difference = 1.5%. Maximum difference = 3.1%. Minimum difference = 0.0%.														
Average difference = 1.5%. Maximum difference = 2.5%. Minimum difference = 0.7%.														
Average difference = .2%. Maximum difference = .4%. Minimum difference = 0%.														

* For clean cast-iron pipe.

which may be put in the more convenient form :

$$v = -1.9709 + 172.889 \sqrt{.0003839600 + R I}.$$

In applying the Chezy formula to all the observations, the value for c that will make the differences between the observed and computed velocities balance is obtained by dividing the sum of the observed velocities by the sum of the square roots of RI , which will make $c = 143.0408$.

In the accompanying table the velocities are computed by the Darcy formula for clean cast-iron pipes, by the Chezy formula with the value of c as derived by Mr. Stearns, and also with the value of c just given, and, finally, by the empirical formula derived from the observations, and given above.

A graphical representation of the computed velocities, given in the table, is shown in the accompanying diagram. The line representing the Chezy formula with $c = 143.0408$ is not plotted, as it would cause confusion. The Darcy formula used is the one quoted by Mr. Stearns for clean cast-iron pipes.

As the formula presented above is purely empirical, and derived from the few observations given for the one size of pipe, it is not claimed to be generally applicable to pipes of different diameters. All that is claimed for it is, that it fits the observations given more closely than the Chezy formula with any constant value for c , and also that it shows that the first observation, which Mr. Stearns discards as anomalous, is normal.

F. P. STEARNS, M. Am. Soc. C. E.—I am inclined to add to Mr. Hering's remarks about Kutter's formula, partly to endorse his advocacy of it, and partly to call attention to some of its defects.

For an endorsement of the formula, I can say that I think it the best formula for *general use* now known, one which will suit fairly well most cases to which a formula for flow in channels will apply, and which will give quite accurate results with small channels under the conditions which ordinarily occur in practice, much more accurate than any formula based upon experiments made prior to those of Darcy and Bazin.

Kutter's formula as applied to brick-lined channels is based upon Darcy and Bazin's experiments, made in a small rectangular brick channel, concerning which Bazin says, that the value of c is too small for brick work executed with care, and that the bricks were not of good

quality, and presented at many points a rather rough surface. They were laid with their flat sides exposed.

Rectilinear channel-sections give smaller co-efficients than curved ones, and this, taken in connection with the roughness of the channel experimented upon, seems to be a good reason for supposing that Kutter's formula ($n=.013$) will give too small results when applied to the usual forms of conduits, lined with well-laid brick masonry.

The Sudbury-Conduit experiments* furnish instances of higher values of c for brick-lining than Kutter's formula, as may be seen by the following examples :

When $R=0.7\frac{1}{2}$ ft., and the inclination is .02 per 100, the value of c given by the experiments is.....	122
By Kutter's formula.....	104
When $R=2.0$ ft. with same inclination, c by the experi- ments is.....	138
By Kutter's formula.....	129
Where the conduit was lined with pure cement ($R=2.0$ feet, inclination .016 per 100), the value of c by the experiment is.....	148
By Kutter's formula ($n=.010$).....	169

In this case the experiment gives *lower* results than the formula.

Kutter's formula is often recommended for calculating sewer discharges. When so used, I think it gives too large results when applied to smooth linings, since sewers in many cases are coated with slime, which forms the surface against which the water flows. The writer has seen such a coating where the velocity was, at times, seven feet per second.

Since the formula is based upon the flow of clean water, the co-efficient (c) should be reduced when estimating the flow of sewage; not because the latter is thick and viscous, but because of the quantity of matter carried in suspension—a quantity which is probably as great when the street washings enter the sewers during storms as it is when only the ordinary volume of sewage is flowing.

* Transactions of the Society, vol. XII, March, 1883, p. 115.

† This value of R agrees with an average of the largest five of Darcy and Bazin's experiments. The average value of c by these experiments was 109, which is identical with the result given by Kutter's formula under the same conditions, thus showing the basis of the formula. The inclination was 0.49 per 100.

The writer has recently made a few experiments upon the Boston Main Drainage Works bearing upon this point. The experiments were made in a straight, covered wooden flume, 6 feet square, made of planed planks, put on lengthwise of the flume, which was free from all obstructions on the inside. When the flume was flowing about half full of ordinary sewage ($R=1.43$, inclination .04 per 100) two experiments gave $c=117$. Kutter's formula for planed plank ($n=.009$), under the same conditions, gives $c=183$. When the flume was full, under a slight pressure, and about three parts of salt water were mixed with one part of sewage ($R=1.5$, inclination .08 per 100), one experiment gave $c=135$, Kutter's formula giving $c=185$. It will be seen that in these cases Kutter's formula gives too high results, and they would still be too high if it were clean water flowing against clean planks. Kutter's value of n (.009) for this category is based upon some experiments made in a channel only 4 inches wide, and its use should be restricted to channels of about this width.

As a condensed statement of my views regarding Kutter's formula, based largely upon the data here given, I will say that, while I advocate the formula as being the *best general one* now known, I would modify it by placing *well laid* brick masonry in the category with unplanned plank-ing ($n=.012$), and by placing well planed timber with well polished pure cement ($n=.010$); even with the latter value of n I would not accept the very high values of c which it gives for channels more than 4 feet in diameter. In estimating the capacity of sewers, I would not use a smaller value of n than .012 for any lining, however smooth, and would deduct from 10 to 20 per cent. from the results then found, to allow for the sewage flowing more slowly than clean water.

Mr. Yonge has taken the equation $v=142.11\sqrt{RI}$ as a pipe formula given by me, though no such use was intended; the equation being a mean value of the experiments used for purposes of comparison with existing formulæ.

If all of the observations were normal, as Mr. Yonge suggests, then the value of c would decrease with the velocity to a certain point, and then increase; thus presenting a peculiarity which is contrary to well established laws relating to the flow of water in pipes. This peculiarity must be embodied in any formula which will fit all of the experiments.

That a formula will agree with such a limited number of experiments proves nothing, since the formula to do so may itself be anomalous; and

that this is the tendency of Mr. Yonge's may be seen by calculating with it the flow in a 48-inch pipe with smaller values of I and v . We find from such calculations these remarkable results: That water with no inclination flows backward through the pipe with a velocity of 1.42 feet per second, and that with an inclination about double that given to the new Croton Aqueduct, the water absolutely refuses to move.

EDWARD B. DORSEY, M. Am. Soc. C. E.—In the paper by Messrs. Fteley and Stearns, on page 117, Vol. XII, are mentioned some experiments on flow of water through a tunnel unlined.

As some gentlemen present probably know the facts connected with those experiments, I would like to ask how rough the surfaces of that tunnel were left; whether they consisted of many rough and small points as would be left by running with the strata through compact limestone where the maximum and minimum diameters would not vary much; or were the faces such as would be left in running through granite or other igneous rock which would be liable to break off in large slabs, showing smooth cleavage or fracture, but giving large variations in maximum and minimum diameters?

F. P. STEARNS, M. Am. Soc. C. E.—In answer to Mr. Dorsey, I will say, that the surfaces of the tunnel were generally in the condition described by him in the latter part of his question. The floor of the tunnel was formed of concrete, so that but about 40 per cent. of the wetted perimeter was the rough rock surface.

WM. R. HUTTON, M. Am. Soc. C. E.—From his experiments on the flow of water in pipes, Darcy concludes that the co-efficients vary with smoothness of the interior surfaces and with the diameter of the pipe. The formula quoted by Mr. Stearns is for new cast-iron pipes. Darcy recommends that for old pipes, which always become more or less rough, these co-efficients be doubled, and that for pipes of smooth glass, and those coated with asphalt, they be multiplied by 0.67. Applying the Darcy formula with these corrections, to the conditions of Mr. Stearns' experiments, and changing to the Chézy form, we obtain for the coefficient 138, or about 3 per cent. less than the mean of those given by those experiments. At a later date, Kutter established a formula, which, conforming more closely to observation in the case of open chan-

nels, introduced the slope into the equation for the co-efficient; the latter increasing with the inclination (in the Chézy form) whenever the mean radius is less than 1 metre. Although the formula is purely empirical, it represents with considerable accuracy the flow in open channels, and we may reason that the same general principles would apply to the flow in pipes. The experiments of Mr. Stearns point in the same direction, and even indicate that in small, smooth channels, the inclination has a greater effect upon the discharge than is shown by the Kutter formula.

Assuming, in the Kutter formula, the co-efficient of rugosity $n = 0.0108$, we obtain the following comparisons:

Value of c , experiment No. 1..computed 141.4, observed 146.37					
"	"	2..	"	143.1,	" 140.14
"	"	3..	"	143.7,	" 142.11
"	"	4..	"	144.1,	" 144.09

The observed co-efficient increasing much more rapidly with the inclination than those computed by Kutter's rule, experiment No. 1 being evidently abnormal.

During the discussion of this paper the question was asked, with reference to a preceding paper by Messrs. Fteley and Stearns upon the Sudbury Conduit, what would be the co-efficient of flow through a rough, unlined tunnel in rock.

There are but few records and experiments upon this subject, which may be at times of great importance. Mr. Hamilton Smith, Jr., M. Am. Soc. C. E., has kindly furnished me with his notes upon a number of small open channels in rock, in which, however, the velocity was very great, and whose alignment contained many sharp curves and bends, producing at such points, he informs me, an evident increase of slope. Applying the Chézy formula to these cases, the co-efficient was found to vary from 30 to 50. The International Commission of 1874 upon the Danube, say that they find the Darcy-Bazin formula, with the co-efficients of the fourth category doubled (those for channels in earth), gives good results for the Iron gate and other rocky rapids of that stream. In 1874 Mr. Bazin published a fifth category, based upon later experiments for rough and rocky beds. More recently Kutter collected a number of experiments upon streams whose beds were very rough, and gives a co-efficient of *rugosity* to be used in his formula for the co-efficient, and since the reading of the paper under discussion, Major Lydecker, United

States Engineers, Chief Engineer of the Washington Aqueduct, has kindly directed gaugings to be made of the flow through one of the rock tunnels of that work, and Captain Symons, of the same corps, Superintending Engineer of the work, sends me the results, which have been reduced.

Mr. A. J. Bowie, Jr., M. Am. Soc. C. E., in a recent paper on mining ditches in California, gives co-efficients for small channels similar to those referred to by Mr. Hamilton Smith, Jr., in which his co-efficient is made to cover all losses by evaporation, filtration, &c., &c. It is not stated that these ditches were in rock.

The results of the foregoing are given in the following table:

Hamilton Smith, Jr. (includes fall due to bends) $c = 30$. to 50.

International Commission on the Danube..... 50.7

Bazin, New Category..... 49.7

Washington Aqueduct, Tunnel No. 1 (fall very slight). 48.0

Kutter, from Swiss Experiments..... 46.36

Bowie (includes losses from evaporation, filtration,
&c).....31. to 45.

We should expect a considerable variation in the results, for the same degree of roughness will not probably exist in any two excavations. The co-efficients will also vary with the velocity, that is with the mean radius and the inclination; neither can the sections upon which the determination of the co-efficient depends be accurately measured in rough rock. The figures, however, may serve as a guide in designing similar works.

Bazin's formula for the relation of mean to maximum velocity, which he found to vary with the roughness of the walls, seems to apply pretty well to the Washington Aqueduct observations, although Major Cunningham (Roorkee Hydraulic Experiments), found it to give erroneous results.

The aqueduct observations also indicate the unreliability of slope formulas when the slope is measured on the *remous* caused by an obstruction; in this case on the curve connecting the slope in the conduit with the reservoir surface. Cunningham, it will be remembered, goes much farther in his statement of the case, and considers that experiments are not entirely reliable if the bottom of the channel at the site is lower than the bottom of any point further down stream.

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COMMERCIAL CITIES: THE LAW OF THEIR BIRTH AND GROWTH.

By ALFRED F. SEARS, M. Am. Soc. C. E.

READ NOVEMBER 5TH, 1884.

WITH DISCUSSION.

It is a part of the experience of every civil engineer who has been much concerned in the development of ways of communication, that the popular judgment often turns on his opinion as to the effect of any certain work on existing towns and the policy of locating new commercial centres.

On account of the influence of railroads and capital in rooting out old stage stations and in building up some prairie towns or manufacturing and suburban villages, it has come to be believed that these agencies are able to control the fortunes of whatever place, and are all that is requisite to bring new cities into being and maintain them in prosperity.

The Atlantic coast is strewn with ruined hopes in the shape of still-born cities, having excellent harbors and abundance of water front, of which the only *raison d'être* is superior facility of access from the ocean.

These harbors, which have not become the important ports they were expected to prove, are generally the object of enterprise, begotten by the virile brain of civil engineers impregnating the waiting capital of speculation.

There has been abundant honesty of purpose in the design, and no excessive credulity in the investment; but there appears a failure to comprehend and appreciate the laws of trade affecting the project.

Thus, while the subject of this paper is outside the domain of physical science, it is within the province of the engineer, and is a matter concerning which he is fairly expected to be informed as an authority.

It becomes, therefore, a proper study for the profession to ascertain if capital is justified in assuming to control the solution of so important a problem, and whether there is not involved, as superior to capital, a natural law, the elucidation of which shall aid in the settlement of these questions.

If, in preparing this paper, it has been found useful to refer to enterprises not yet released from the field of speculation, it is without the intention to advertise the chances for or against any scheme, the sole object being to gather facts that may be formulated into an expression of law as a scientific demonstration. As this investigation proceeds, the problem undertaken appears so clear, and the conclusions so natural and just, that one is almost deterred by their simplicity from stating them so formally. But when we reflect that, however clear and natural and just the truth seems to be, many of the wisest men of affairs are constantly failing in this field, we recognize the necessity for such a statement as shall make it not only positive, but tangible, and remove as far as can be, a certain class of speculation from the region of chimera to a field of certainty.

Forty years ago, when the *Unicorn*, the pioneer steamer of the Cunard line, entered Boston harbor, the merchants of that enterprising town felt assured of commercial triumph in the race with New York, because they were twenty-four hours nearer Liverpool than their sister city.

Some not too "wise men of Gotham" were alarmed, and wondered if they had not committed an error when they settled in the Dutch metropolis, although the population of New York was 300,000 and Boston contained but a third of that number.

To-day New York is the centre of a population of three million souls, and Boston of but little more than a half million.

A steamer leaves New York daily for Liverpool, and another sails once a week from Boston.

To the wonderment of the Boston merchants, New York and not Boston has become the commercial metropolis of the country.

In those days Boston boasted the one or two wealthy men of America. A Boston bank note was as current all over the country forty years ago as a national bill of the present time. This could never be said of the New York banks, nor of any other city in the United States.

The Boston business man figured up the situation logically, as it appeared on the surface of things, quite in his favor. He said: We have the American port nearest Europe by 24 hours; we have an enormous capital, and can offer trade every facility it demands; we have the most intelligent population, the purest municipal government, the highest reputation for commercial honor; all this with extraordinary business liberality and enterprise. "The solid men of Boston" stood for a business proverb.

Nevertheless, New York has pushed ahead, and no amount of money expended by Boston to tap by a short route the western country north of New York, or to draw traffic directly from New York by shorter railway lines, has yet effected the object of the projectors, or is likely to.

On investigation, this result appears in harmony with a natural order independent of the enterprise, wealth and character of merchants.

New York is more than 200 miles nearer the heart of the country than Boston. This made her advantage. The moving mass, that seeks transportation, reckons that distance to be as nothing on the ocean, compared with the cost of movement on land or river.

The cargo of a great steamer transported between New York and Boston forty years ago would have demanded the service of ten locomotives and four hundred cars. On board the ocean steamer it represents only the comparatively inexpensive continuance of her voyage for another day.

New York and Boston are not sole examples of such a relation of things. Going south, we find that every commercial port has been made the mark of ambitious rivals, under the mistaken apprehension that an error was committed in the original location.

Thus, Philadelphia on the Delaware, 120 miles from the ocean, has

grown into grand proportions, and continues to grow, in spite of the desperate exertions of two or three ports greatly nearer the highway of nations. Commerce refuses to be persuaded to avoid a tedious navigation against the chances of head winds in a narrow roadway and avail itself of a port easy of access in the lower bay.

Another instance of the perversity of commerce in passing by great advantages to get up stream is witnessed in the position of Baltimore, 108 miles from Hampton Roads.

Circumstances of the Civil War led to the development by northern capital of one of those enterprises on the southern coast that was to revolutionize the commerce of the region and destroy the two old cities of Savannah and Charleston. A harbor nearer the sea and accessible to vastly greater ships than can enter Charleston was found at Port Royal, which, it was believed, would drain both those towns of their wealth and population. Capital seized the point and tapped the neighboring country with its railroad. Streets, wharves, warehouses, corner lots and advertisements flourished for a time. But Port Royal is a dull, insignificant shipping station, while Charleston and Savannah remain live cities.

For 30 years capital has struggled to build a commercial city at Brunswick, Georgia, in rivalry with Savannah. The capital and the superior facilities and the 22 feet of water on the bar all still exist there, but as yet no important port has arisen from their ingenious combination.

A rather interesting experience of similar character is found in the history of Jacksonville and Fernandina, on the coast of Florida; both places insignificant, to be sure, but serving our present purpose of illustration.

Jacksonville is on the St. John's River, 25 miles from its mouth, at a point where, after descending its whole course toward the north, it turns abruptly eastward and flows directly to the ocean. At this elbow the stream becomes a broad, grand river, so that vessels which cross the bar can reach the town under sail.

The twenty-five miles from the ocean is just that distance inland, since its course is normal to the coast.

At the best of times, 13 feet of water can be taken in, but vessels often have to wait the abatement of a gale before making the venture. It would be difficult to find a more dreaded bar on the coast.

When the enterprise which located itself at Fernandina was begun in 1857, Jacksonville had a population not exceeding fifteen hundred souls.

Fernandina was 65 miles farther north, and by so much nearer the world. Ships drawing 19 feet entered there on ordinary tides, while 22 feet can be carried in during the spring floods of each month.

Few enterprises have had the advantage of more distinguished advertising than Fernandina. By the energy and influence of a leading member of the National Senate the place seemed, in some sort, a pet of the Government. Army engineers surveyed, located and built the railroad from Fernandina to the Gulf, and no approach to any harbor on the Atlantic coast was so well buoyed as the bar of Cumberland Sound.

An immense gift of land aided in the construction of works and purchase of material, and the hopeful speculators of the place had the supreme satisfaction of seeing iron shipped to their port for the Jacksonville Railroad rather than encounter the dangers of the St. John's bar.

The two railroad lines, stretching from these points to the interior, crossed each other in the pine forest at a distance of 19 miles from Jacksonville and 47 miles from Fernandina. So Jacksonville was 28 miles nearer the heart of the country than its rival; and, moreover, was situated on a fine river, watering a region thus made tributary to the town and reducing cost of transportation to a point below that which permits any land-line to be its competitor.

When the war came upon that coast both places were abandoned by the native population, and after its close both became objective points of interest to northern emigrants.

The uniform result has followed. Fernandina is a respectable village, with a population of twenty-five hundred souls, while Jacksonville has already fifteen thousand inhabitants.

Nor is this condition of things confined to the American Continent; Europe presents similar illustrations. Glasgow, on the Clyde, owes its wonderful growth and prosperity to its position at the head of navigation—an artificial harbor, made practicable by its propinquity to the coal and iron of the country. Sixty years ago a grown man could wade the Clyde at Glasgow without wetting his shoulders, and to-day no ship is engaged in the commerce of the world that fears to charter for that port.

Time was when wise men thought to build a port on the Elbe, below Hamburg, and Altoona was started as a rival to the great capital. It had the backing of a patriotic and ambitious government, and for a time did seem to threaten the existence of the ancient port. At present, however, it is only the suburban home of the successful retired Hamburg merchant, and the ships pass it by to enter the Hamburg docks.

If the Atlantic coast is prolific in illustrations for this study, the Northwest territory, along the valley of the Columbia and the shores of Puget Sound, also abounds in lessons to the same end.

The relation to the commercial world of Astoria, on the Columbia River, is an interesting instance of the conflict of capital with law in the attempt to regulate commerce.

Founded by one of the wealthiest, most enterprising and far-seeing citizens of the country, it became, as it was intended by him to become, the depot of the fur trade of the Northwest. But when the fur trade failed, and simply a home market existed for the salmon of the Columbia, the men who had staked their fortunes or their hopes on that important point beheld with new satisfaction the settlement by Americans of the great Willamette Valley above them. It was a natural expectation that Astoria would become the port of the region.

It has grown continually, and is still growing, but this town, situated but a few miles above the Columbia River bar, with a life covering three-quarters of a century, has during the last twenty-five years seen Portland come into being a hundred miles above, and attain a population of 40 000, while Astoria has never yet sheltered more than 3 000 souls.

Fourteen years ago, capitalists interested in developing the promising points along the route of the Northern Pacific Railroad determined that the Columbia terminus of the Pacific Division of that line, sixty miles above Astoria, must become the commercial port of that great river system, and the town of Kalama was located where stream and railroad were designed to meet.

Maps were prepared, hotels and churches erected, elevators, warehouses and great docks projected; and the line of the Northern Pacific Railroad built hence to Puget Sound.

By virtue of its future outlook, Kalama became a county seat. Corner lots in the heart of the town plat sold for \$3 000 each; water lots were laid out along the river bank, and sold for the sum of nearly \$3 000 per 100 feet of frontage.

Kalama still exists, but only in name. The Columbia River still flows by its site, as broad and deep as when Jay Cooke made note of its promise ; but the once well-filled churches are abandoned for want of congregations ; a corner of the grand hotel serves the purpose of courthouse and jail ; the splendid water lots still remain under the shadow of primeval trees, the only improvement they have experienced being in a reduction of annual tax from \$28 to 14 cents.

And yet this bubble was the scheme of men eminent for wisdom. It was inspired by eminent engineers and accepted by intelligent capitalists. Nor can there be any doubt of the uprightness of intention when we consider the high character of the men who gave the project their approval and practical endorsement.

Kalama is but one of several similar experiments that have sprung from the fruitful womb of Northwestern enterprise.

It would seem that a sufficient statement of fact has now been presented to justify a consideration of the premises that immediately determine the location of a commercial port.

The producer of a given region, whether artisan or farmer, will deliver his wares at such point as will entail on him the least cost of transportation ; he goes to the port that he can reach by the shortest road.

Again, there is never competition to sell among producers. Hence they are outside the struggles of trade ; they are not found crowding forward toward the purchaser, the agent of the consumer, the exporting merchant. Indeed, the chances are that crops will be sold in the first instance on the soil that bore them.

If producers were competitors, commercial towns would be pushed toward the sea to catch the first chance at the customer from abroad ; and farmers, turned speculating capitalists, would become the originators and managers of railroad lines. On the contrary, the agents of the consumers, the merchants, who send the crops abroad and import the goods they barter in exchange, are the men who jostle each other in the marts, who push into the interior of a country, to get as near to the field of produce as they can reach.

Thus it is that a great commercial city cannot be reared near the coast at any site which a large ship can pass and sail inland to load or even unload.

From all these elements we deduce the proposition that: *The commercial port of a region will be as close to the producer as it is possible to go, and obtain reasonably good facilities for the class of transportation demanded by the produce of the country.*

This is the law—the inexorable, immutable law, without exception, in the world's economy.

Nevertheless, not a decade passes without adding a new experiment to the list of failures; and the failure has been universal, so far as the destruction of the inland port has been concerned. We are not free to accuse shrewd business men of attempting to oppose their own force to established law; but we may fairly suppose, and we repeat it, that the law has not been apprehended, or, at least, that its value has not been appreciated. If we may judge by the common argument, we are justified in believing that the greater number of intelligent men of enterprise consider the location of capital at a given point by far the most important factor in determining the location of towns and ports; and this is precisely their blunder.

It is difficult to account for the singular persistency with which this mistake of capital is repeated, since, in whatever direction we turn, the one law is exemplified—the one lesson taught. In accordance with this law, Montevideo, on the outer coast of South America, has a population of forty thousand, while Buenos Ayres, a hundred and thirty miles up the river, contains nearly a half million inhabitants. Guayaquil, in the edge of a sickening swamp, might have been healthily placed forty miles further down stream, at a point famed for its salubrity, imposing forty miles less of river navigation with equally good anchorage and better potable water for a population. The expense of transporting the products of the country by the agency of native boatmen on *balsas* or in canoes to a situation where whites can live without fear of malignant fevers, would be trifling indeed; but such a course would separate the speculator from his game, the cocoa, hides and woods of the country, and the merchant from his customers, the producers of those articles, by all that distance of forty miles.

Thus far we have demonstrated the law by which the great commercial city of a region becomes established, and we have attempted to show the impracticability of building up between the centre of production and the sea a rival port of sufficient importance to seriously affect the stability of such a city.

There now occurs an important consideration bearing on the question, which was barely touched in discussing the relative positions of New York and Boston. It was said that Boston capital has tapped the country north of New York in the hope of drawing off Western trade to itself. The result of the Western Railroad has not been what was expected of it. Troy and Albany were at nearly equal distances from New York and Boston, but the immense capital of the Eastern city failed to seize the produce of the West. The enterprising Bostonian saw that a mountain intervened, and he pierced the obstacle, reducing the difficulties of transportation to their lowest terms. Still, he has always to contend against one radical truth, which he is either ignoring or striving to eliminate from existence by the persistent employment of capital. This truth is, that trade follows natural channels; that the staple products of the soil and all the coarse minerals will reach the coast by the route that permits the easiest movement with least artificial aid.

The trade of a country will not cross a great valley even to reach a market of the first importance. It will either create centres of exchange in such valleys or, having reached them, follow down their course to a port. Thus, Western produce reaching the Hudson will follow that stream to New York for exportation.

In the Northwest, the relation of Portland on the Willamette to Puget Sound closely resembles that existing between the ports of New York and Boston. Portland occupies the site of a great commercial centre for an immense region. All the country west of the Rocky Mountains tributary to the Northern Pacific Railroad and seeking an outlet on the coast will, on going westward, make Ainsworth, at the mouth of Snake River on the Columbia, a common point of departure for Puget Sound as for Portland; from Ainsworth the trade will either descend the great valley or, proceeding along the projected line of railroad, cross the Cascade range and enter a Puget Sound harbor.

Here occurs a problem the solution of which is peculiarly the duty of the civil engineer.

The lineal distance from Ainsworth to Puget Sound differs but little from the distance to Portland.

In this case there is a descent of more than 300 feet along the Columbia River in favor of west-bound traffic.

In the other a summit of 2400 feet is to be overcome, besides the curvatures of a sinous mountain line and the increased cost of constructing a line with fairly practicable grades. These resistances, to be encountered in operating, the engineer will equate with their value in level tangent before determining which terminus is most accessible to the interior.

In looking over the American sea-coast it is difficult to find room for more speculations of this class than those now presented in the extreme Northwest. But the student will find an abundant field for observation, which he cannot fail to regard with interest, in the development of commercial cities along the eastern coast of South America, where in the present and the next generations will be opened up innumerable grand enterprises in regions now unoccupied, save by the india-rubber hunter and the crocodile.

DISCUSSION.

JOHN BOGART, M. Am. Soc. C. E.—The proposition advanced by Mr. Sears, that "a great commercial city cannot be reared near the coast at any site which a large ship can pass and sail inland to load or even unload," seems inapplicable to the port of New York. The Hudson River is navigable for large ships at least seventy-five or one hundred miles above New York.

ALFRED F. SEARS, M. Am. Soc. C. E.—The question raised by Mr. Bogart is most interesting and important, and demands a careful analysis of the geographical and commercial situation through its history.

By the law announced in the paper under discussion, it would seem that ships ought not to stop at New York, but go on up North River to the head of ship navigation.

If New York had been intended as the commercial port of the Hudson River valley, this would be true; but the fact is, it was not the port of that valley until its importance forced tribute from or absorbed every community within its reach.

Albany, settled in 1614, was the all-sufficient port of the upper Hudson until increased population and development gave the region a line of foreign commerce, and Hudson, at the head of ship navigation, 116

miles above New York, became the port of the valley, maintaining an amount of shipping superior to that of our great metropolis, and carrying on trade with the West Indies and Europe, besides its enterprise of whaling and the fisheries.

But the valley of the Hudson is restricted in breadth; there was no great extent of country to seek its waters; going up the Hudson was not approaching the heart of any great producing region.

The birth of New York in 1623 was an existence quite independent of the river valley. It was the centre of an immense coast system, including Manhattan, Long and Staten Islands; New Jersey, directly west, and the shores of Connecticut. The valleys of the Passaic and Hackensack, and all the country back of the precipitous west bank of North River found the Manhattan port more accessible than other points.

Meanwhile Elizabeth and Newark became the centres of promising agricultural and manufacturing districts, and naturally brought their commercial exchange to New York as the nearest port.

In 1812 the Act of Embargo destroyed the foreign commerce of Hudson, which was henceforth transferred to New York. But, so late as this date, the population of Philadelphia, so much nearer the heart of the country, was greater than that of New York, and remained so until work on the Erie Canal had progressed three years and made the canal a certainty.

The belief in this certainty gave impetus to values immediately along the line and in all the valley of the Hudson.

When the canal was opened the New York merchant sent forward his agents to buy up grain and ship to his port, so that if London, Liverpool and Hamburg were principal grain markets in the world, New York stood in the same category, and its population was doubled in the decade that saw the canal finished.

New York, therefore, is not simply the commercial port of the Hudson River valley, but of half the continent, and owes its position, not to its accessibility from the ocean, but to its central location with relation to the producing region directly west and southwest, as well as northwest.

It would be an exceedingly nice problem to investigate thoroughly the history of our commerce in its relation to the growth of our principal commercial centre, but the present study is necessarily brief.

GEORGE S. MORISON, M. Am. Soc. C. E.—Major Sears, in his paper on the birth and growth of commercial cities, claims to have found an inexorable law without exception, that "the commercial port of a region will be as close to the producer as it is possible to go and obtain reasonably good facilities for the class of transportation demanded by the produce of the country." The statement is exceedingly strong, and he adduces many instances which indicate that commercial cities have been developed on this basis. No amount of evidence, however, will prove that a law is without exception in the world's economy, if a single instance can be found to the contrary.

That the general principles of such a law are correct cannot be denied. A commercial port from its very nature, as being the gate through which the commerce of the interior must pass to the ocean, requires convenient means of access to the interior. Between ports which have equally good communication with foreign lands, that is, equally good harbors, the one which has the best communication with the interior productive country may be expected to win. It does not follow, however, that, when there is a marked difference in the character of the harbors, as well as in the means of communication with the interior, the latter point alone will decide. It would certainly seem right that there should be some balancing principle, and that superior advantages in the matter of harbor could overcome a portion of the disadvantage in the communication with the interior. In other words, the port which is on the line of the cheapest through transportation, where the sum of the cost of land and water carriage is the least, is the one from which most may be expected. In cases where there is not too great a difference in the total cost of carriage by both land and water, local circumstances will probably shape the character of a town; the enterprise of its population, the accident of its having been established first, and with these very likely cheap land transportation may count for somewhat more than cheap water transportation by itself.

When we consider the actual circumstances of the growth of cities, it must be remembered that nearly all the principal seaports of this country were established and held a rank which approximates to their present relative rank before the construction of railroads. The concentration of capital at the Atlantic cities made these cities the focal point of business before the great change took effect, which has reduced the cost of transportation to a small percentage of what it was when these

cities were built. This may be said of every important port from Portland, Maine, to New Orleans. They all owe the details of their location to circumstances which preceded the present conditions of transportation. The case of New York against Boston is cited. The local advantages of New York over Boston are not merely that New York is nearer the producing country of the interior (practically the difference is only 60 miles instead of 200), but New York harbor is a better harbor than Boston harbor; it is no deeper, but it is a safer harbor to approach in rough weather, and a much more commodious and convenient harbor when once entered.

On the western Gulf coast and on the Pacific coast occur the two instances of the most modern development of commercial ports.

Galveston has grown up as the commercial port of Texas; it is the only Texan port having a tolerably good harbor, but ocean-going vessels can be taken up nearly to Houston, and with a small expenditure of money a port could have been built up at some interior point on Galveston Bay. Galveston is built on a sand-bar, practically fifty miles from any agricultural country, directly on the Gulf, and, while the wharves on the inside are in a well protected harbor, the island on which the city is built is exposed to the violent action of the Gulf waves. The City of Houston is fifty miles nearer the agricultural portions of the State; the railroads centre at Houston, and a single line connects Houston with Galveston; still Galveston is the commercial metropolis of Texas; it has become so because its wharves could be reached with less difficulty than those of Houston, or even of Harrisburg, at the mouth of Buffalo Bayou.

On the Pacific coast, there is the case of San Francisco. San Francisco lies between San Francisco Bay and the ocean; it is on a narrow peninsula, with little good country near it, and may be said to be separated from the whole agricultural portion of California. Before the introduction of hydraulic mining, good sized vessels could go up to Sacramento, and the largest class of sailing vessels still take their cargoes from Benicia. On the basis of the law which Major Sears claims, Sacramento, which is in the heart of the great valley of California, and which is as much nearer the original mining districts as it is to the agricultural districts, ought to have become the commercial metropolis of California, and the Sacramento River should have been improved instead of being allowed to deteriorate. If, however, the difficulties of river

communication would seem too great, a city ought to have grown up at Benicia, or some point above that. The facts are precisely the reverse.

Referring now to the case of Portland as against Puget Sound. Portland is somewhat more than one hundred miles from the coast, on the Willamette River, a short distance from its junction with the Columbia. It lies at the mouth of the Willamette Valley, which is the oldest agricultural portion of Oregon. The bar at the mouth of the Columbia River is a source of serious delays to vessels entering the river, and shoal water in the river compels the lighterage of a portion of the cargo at almost all seasons. These difficulties represent a cost of not less than \$1.50 per ton. In other words, the cost of chartering a vessel to take a cargo from Portland, with allowance for lighterage, etc., is, at least, \$1.50 per ton more than to take the cargo from a port on Puget Sound. The improvement of the channel between Portland and Astoria and the securing of deep water over the bar of the Columbia have been considered, and are both feasible; they are operations, however, which will take much time and money. At present the position of Portland is as above described. A rate of \$1.50 per ton, at the rates which the trunk lines are now receiving for their through business, represents three hundred miles of railroad transportation. The actual distance, as stated by Major Sears, from a common point in the productive country east of the Cascade Mountains, to Puget Sound and to Portland is about the same. A railroad is built down the Columbia Valley from Ainsworth to Portland. A railroad is building across the Cascade Mountains to Puget Sound. The cost of transportation by the two routes will not differ materially, but this is due to the poor location of the road along the Columbia River. If both roads were built on a thoroughly first-class standard, the one down the Columbia River would be a low-grade route throughout. The other one would be a low-grade road, except for about twenty-five miles in each direction, where assisting power would have to be used in climbing the mountain grades. If we assume the cost of the assisting power to take a train up a mountain grade to be twice as much per mile as the present rates received by the trunk lines for their through freight (a supposition which is certainly too high), the actual cost of taking this business to Puget Sound instead of to Portland would be about 25 cents per ton. This would still leave an advantage of \$1.25 per ton in favor of the Puget Sound port. This increased cost (which will not exist until the road along the Columbia River is improved) would

probably be borne by the railroad as increased expenses, and not charged to the shipper; but assuming it to be borne by the shipper, it would still give a sufficient advantage to a Puget Sound port for the handling of all business from east of the Cascade Mountains to divert the trade in that direction. Portland may continue the largest city of this part of the country for many years. It will have the trade of the Willamette Valley to live upon, and its banks and merchants may handle the business which does not pass through their own city, this condition not being unlike the condition which is likely to exist between St. Paul and the port at the west end of Lake Superior.

ALFRED F. SEARS, M. Am. Soc. C. E.—In replying to Mr. Morison's remarks, may I be permitted to premise that if what I have laid down as law admits of exception, it has no claim to be called law. It may be a general rule in political economy, but it is not law.

I claim, however, to have stated a natural law—a law in political philosophy; and I have shown how the violation of its principles has been met by the constant penalty of violated law, *i. e.*, by sacrifice, loss and failure.

Mr. Morison has reiterated the old mistake, when he declares that "the port which is on the line of the cheapest through transportation, where the sum of the cost of land and water carriage is the least, is the one from which most may be expected." This statement reduces a commercial port to a shipping point, and nothing more; whereas it is that point which, having all the advantages of shipping demanded by its class of transportation, affords at the same time the closest approach of the merchant to the producer with whom he is bartering his importations.

As attention has already been given to the port of New York, it will scarcely be necessary to refer to it again; so that I pass to consider Mr. Morison's reference to the Texan port.

Galveston can hardly be called a harbor. Like all Texan ports it is an open roadstead; safe certain months in the year, and dangerous at others. Still, it is the best to be had, Houston being inaccessible, save under exceptional circumstances. Now, the law, as stated in this paper, is that a port shall afford "reasonably good facilities for the class of transportation demanded by the produce of the country." Galveston approaches this condition nearer than any other port by a vast difference, and, therefore, Galveston is the port.

What can be done by a small outlay of money cannot as yet be fairly considered, for Texas is still a new country, and must accommodate itself, for the present, with the facilities it possesses for its very limited amount of shipping. Glasgow is an example of what an outlay of money in the way of improving a channel will accomplish, and perhaps Houston may one day be another: but as yet the money has not been expended.

As to San Francisco, it has a position much like that of New York, it being the centre of an extensive coast system.

These form no exceptions to the law stated in this paper, nor even modifications of its absolute truth.

Sacramento is the port of the upper river as Benicia is the port of the lower Sacramento, receiving the products of the San Joaquin Valley. Tributary to them is a population of more than 200 000 inhabitants.

But San Francisco is the port of a distinct region. It is not only the convenient harbor of all the lower bay with a population of 180 000, outside of its own municipal limits, but is the only first-class harbor on the coast between Monterey and the Columbia River, a region with an additional population of 250 000 souls.

As the little ports on the coast bring their tribute to a mart, they must find a harbor as near at hand as possible. The coast with the Bay shores is the producing region for San Francisco, and it is located, therefore, where it is, not to be accessible to the ocean, to Yokohama and Hong Kong, nor yet to the Sacramento Valley, which has its own port, as admitted by Mr. Morison, but to the numberless inlets along the Pacific shores north and south of there, which ship their produce in schooners and small steamers to the nearest great harbor.

Like New York, being the centre of varied products from a vast area, San Francisco is a convenient manufacturing point and has become the port of a population of 700 000 souls, not including the Sacramento and San Joaquin valleys. On this account it has become a commercial market, and has absorbed the capital of the inferior river ports. Without New York and San Francisco, the valleys above them would ship directly to Liverpool or some other market. That has become unnecessary; they find the market at their doors, and ship to New York and San Francisco from their own up-stream local ports.

If San Francisco did not exist for the reasons thus stated it would not exist at all.

And so far is San Francisco from being "separated," as Mr. Morison says, "from the whole agricultural portion of California," that, if we consider the Sacramento and San Joaquin valleys fairly tributary to Benicia, while the shores of the Bay below Benicia and the sparsely settled coast are tributaries of San Francisco, the value of farms in the former district according to the last census is less than \$122 000 000 against more than \$112 000 000 in what I have called the San Francisco district; and the valley region produces but \$16 000 000 a year in manufactured goods against \$115 000 000 for the bay and coast.

It seems safe, therefore, to say that San Francisco has a *raison d'être* quite in accordance with the law as I have ventured to state it.

Liverpool, another great market of the world, owes no considerable part of its importance to the trade of the Mersey. It is also a great coast centre, reaching out to the Irish as well as the English coast, and but for the immense expenditure in docks would be as independent of the caprices of capital for prosperity as any other city.

As to the claim that one of the great markets of the world may yet grow up on the shores of Puget Sound, it would be saying too much to contest it. But if it is claimed that the operations of any railroad company and of individual capitalists, specially directed to that end, can produce such a result, it must be answered that enough has been shown to prove the futility of such enterprise.

It is a problem offering many elements for an exact solution; if the result of such a solution favors the birth of a metropolis on the Sound, the capital of rival ports cannot stay its growth any more than capital can build it up against law. But it was no part of my design to enter on such a speculation in this paper, which, after all, with no more data than I now possess would be nothing but a speculation. Nevertheless, I must correct a statement of Mr. Morison that I stated the "actual distance from a common point in the productive country east of the Cascade Mountains to Puget Sound and to Portland is about the same."

I was careful to say the "lineal" and not the "actual" distance, and I further suggested the elements of resistance to be added to this lineal distance to make up what may properly be called the actual distance. I did not intend making any definite statement containing figures, because it was not possible to present the data on which they are based. And yet, as Mr. Morison has stated his conviction about the cost of operating, I may, perhaps, be permitted to say, I am well convinced

that it will cost twice as much to carry a ton of freight from Ainsworth to Puget Sound as from Ainsworth to Portland; even considering the wretched blundering in constructing the line down the valley of the Columbia.

Mr. Morison dwells with some emphasis on a point of more importance than appears at first view. As I understand him, the commercial ports of our coast were founded before the existence of modern facilities for transportation; having become established and capital being located, they have maintained their positions as commercial centres, although we cannot say they would have been so located if the railroad systems of the country had first been built.

Now, this is an important statement, though unsupported by the facts. It is important, because it is the sort of reasoning that has led to a vast dissipation of capital. The truth is, and this statement is one proof of it, that the commercial ports of the country have grown up in accordance with natural law, when men were without artificial means to help them; they are, therefore, instinctive or intuitive locations. So true is this, that one cannot state the case of a new commercial port started by the influence of capital and railroads in rivalry or opposition to one of the old ports, that has been a success, that has not indeed been a pronounced failure, and there are many such attempts. I challenge the mention of a commercial port, the relation of which to its neighboring ports has been changed by the influence of railroads or the forcing of capital.

Of course, railroads have increased the commercial wealth and machinery, but as yet they have not, and I dare to say they never will, divert trade from the line of direction of natural channels, as laid down in the paper now under discussion.

Every new commercial port undertaken by railroad capitalists has been a failure in reaching the fulfillments of its promises, and such enterprises must continue to be failures.